Multiscale Modeling of Red Blood Cells Passing through the Human Spleen

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Why do we care about Red Blood Cells?

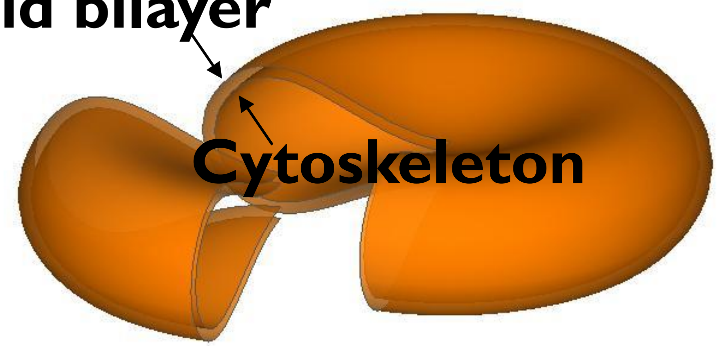
Beautiful Shape

- Carry oxygen by hemoglobin
- Beautiful biconcave resting shape
- Simplest but strong structure

    Lack a nucleus

    No complex organelles

    Flexible and strong cell membrane

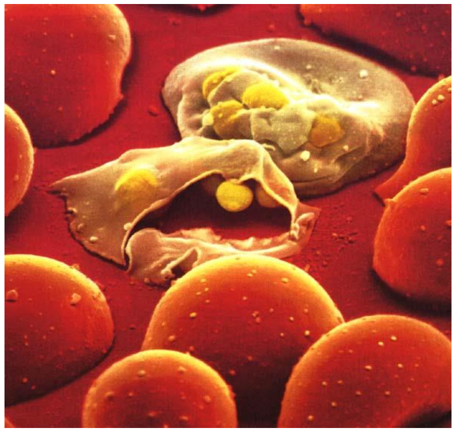


Two-layer FEM model

(Peng *et al. Physical Review E.* 2010)

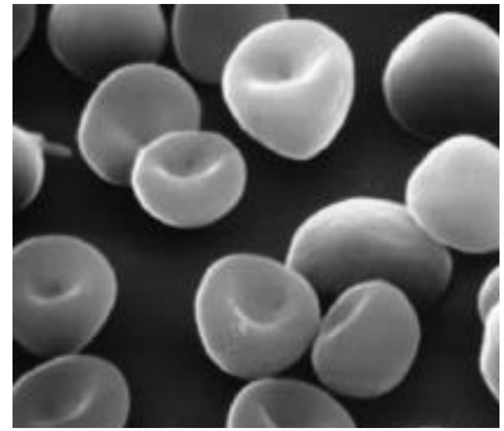
Red Blood Cell Diseases

More than 1 billion people (1 in 6) suffer from RBC diseases, e.g. malaria, anemia, sickle cell disease, (Mohandas *et al. Blood* 2008)



Malaria

Sickle cell disease



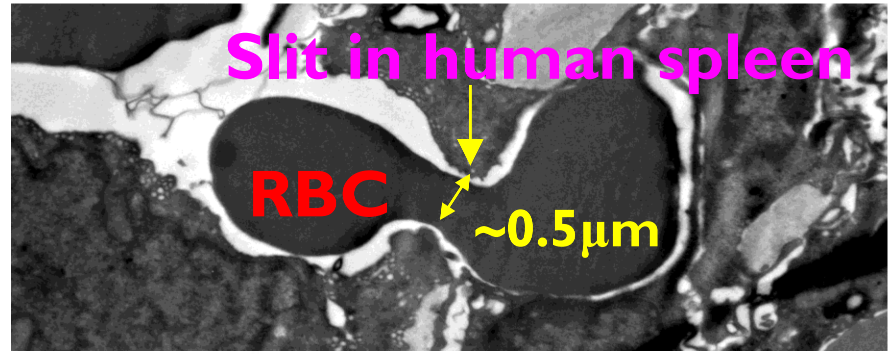
Anemia/Hereditary spherocytosis

1 million deaths per year in Africa

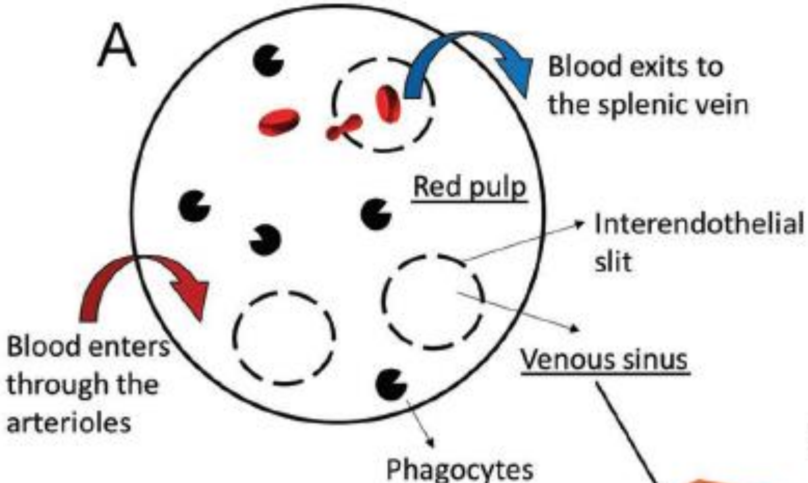
1 in 5000 in America

Diseases .vs. mechanical properties, structural stability of RBCs

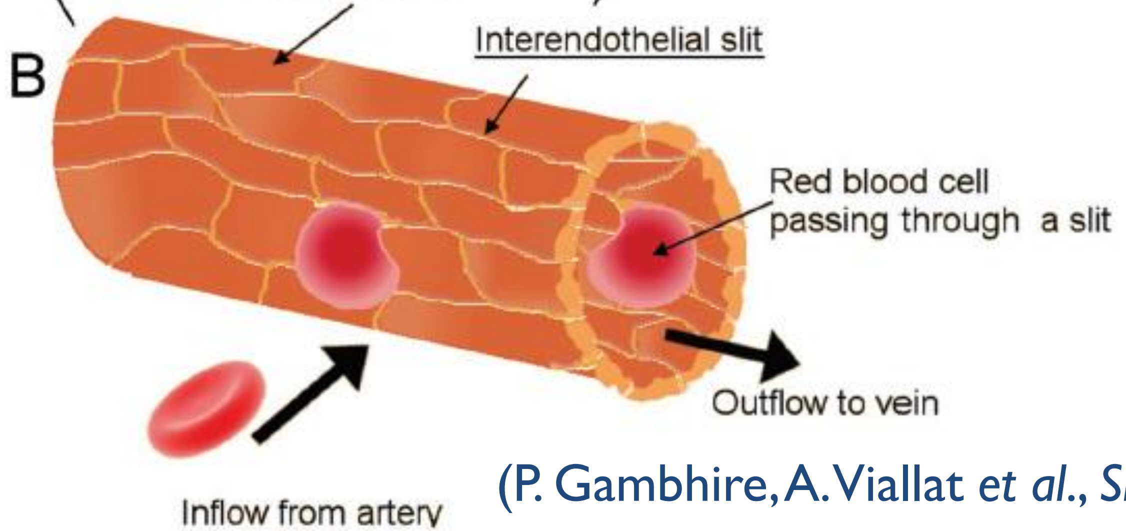
RBCs Transmigrating through Inter-endothelial Slits in the Human Spleen



Strong Structure (Buffet *et al. Blood*, 2011)



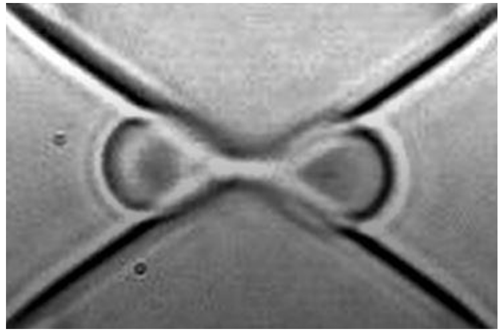
(P. Gambhire, A. Viallat *et al.*, *Small*, 2017)



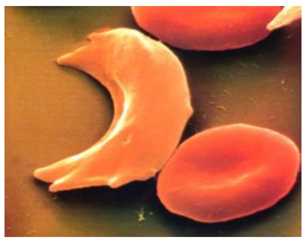
(P. Gambhire, A. Viallat *et al.*, *Small*, 2017)

Experimental Work: Different Cell Shapes When Cell pass through Microfluidic Slits

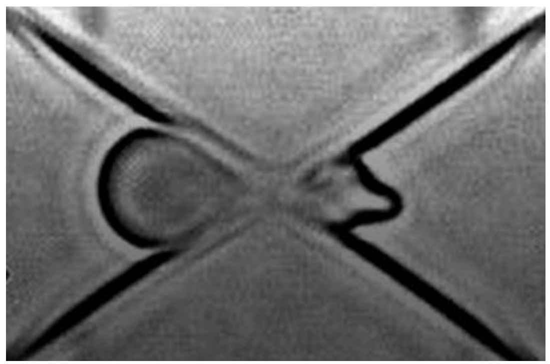
Healthy RBC



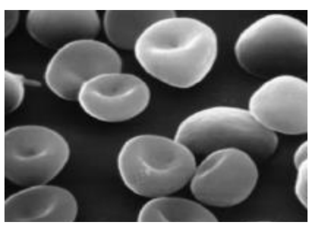
Round shape



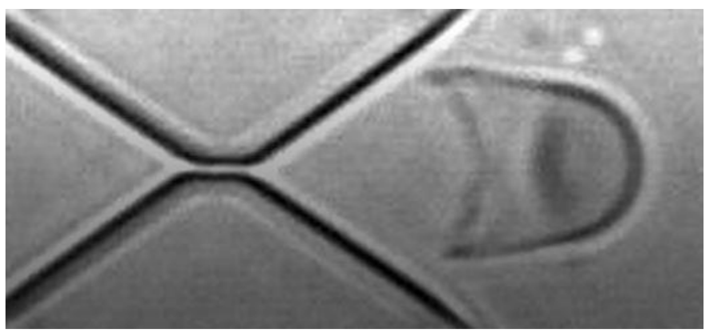
Sickle Cell



A small tip formed



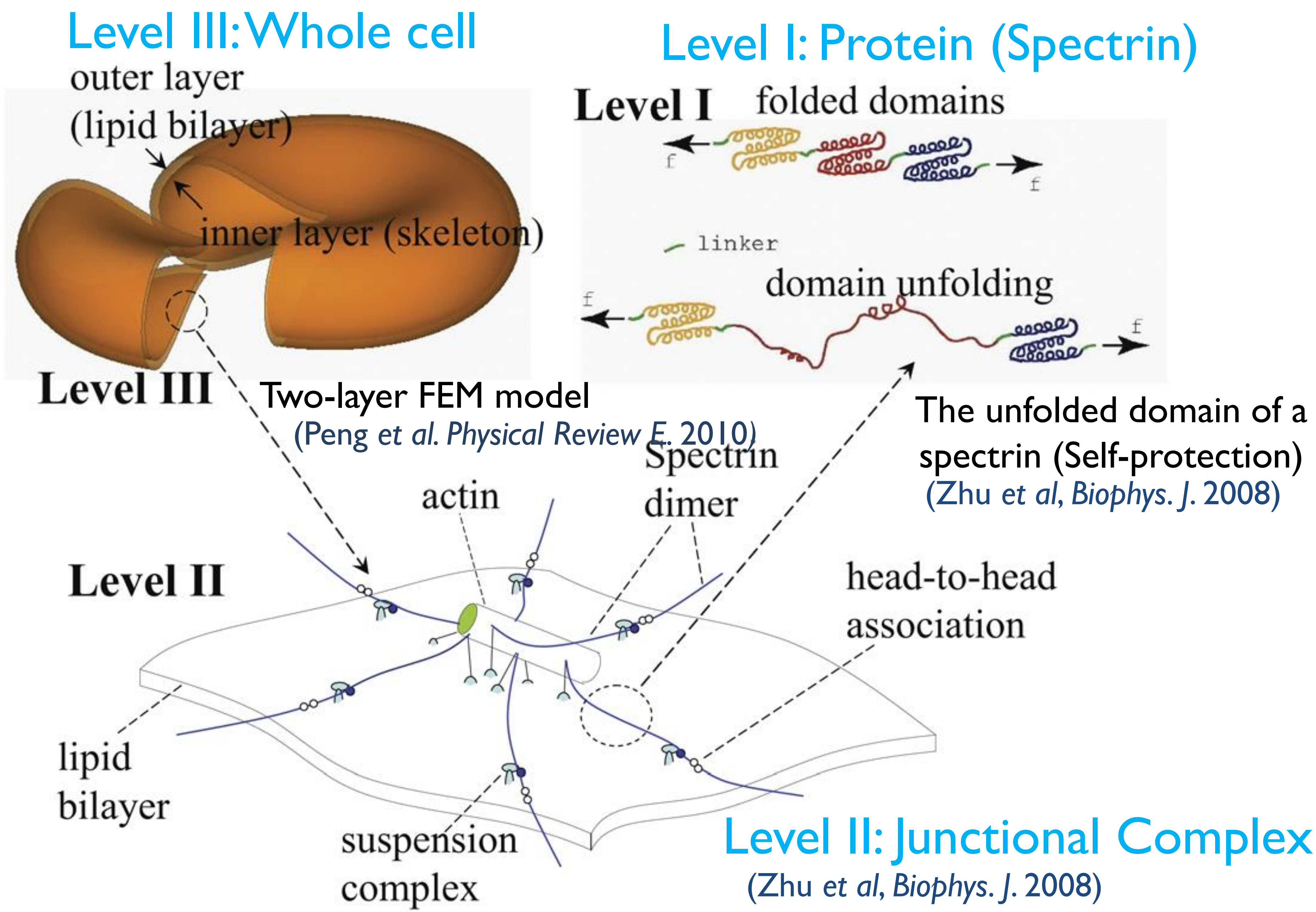
Anemia Cell



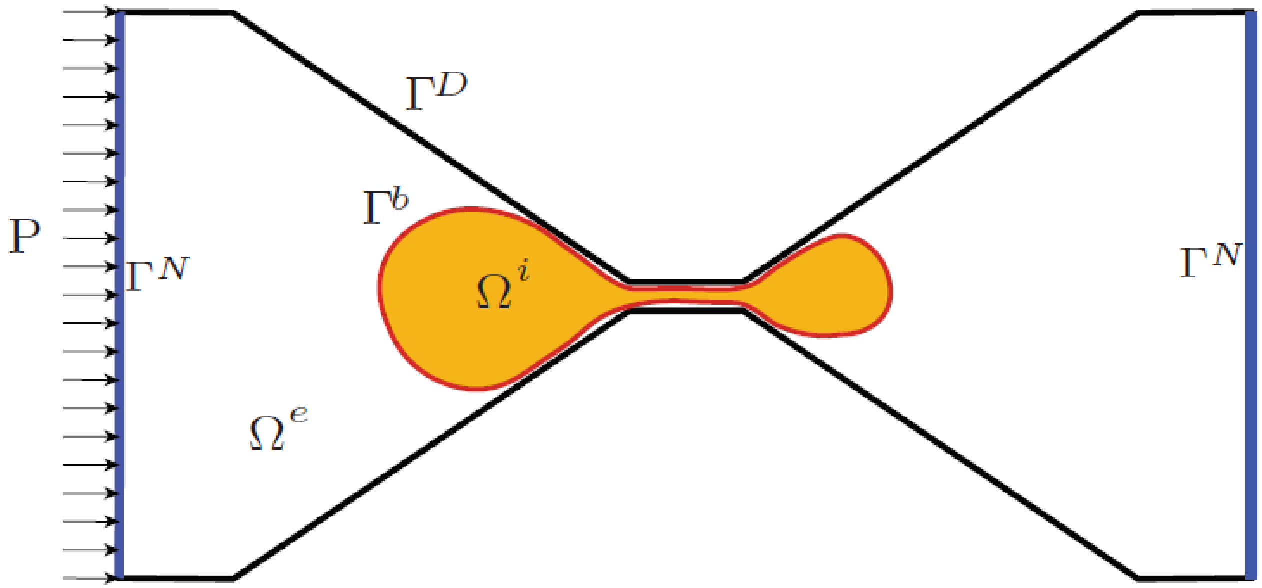
Two broken tails formed

P. Gambhire, A. Viallat *et al.*, *Small*, 2017

Three-level Hierarchical Multiscale RBC Models



Boundary Integral Formulation of Elastic Capsules in Stokes Flow



Stokes Flow: $\eta \nabla^2 \mathbf{u} = \nabla p,$ $\quad\Longrightarrow\quad$ Boundary Element Method

$$\nabla \cdot \mathbf{u} = 0.$$

Lipid Bilayer: $\nabla \cdot \Theta^b = 0,$ $\quad\Longrightarrow\quad$ Finite Element Method

Boundary Conditions: $u = \bar{u} \quad \text{on} \quad \Gamma^{\mathrm{D}},$

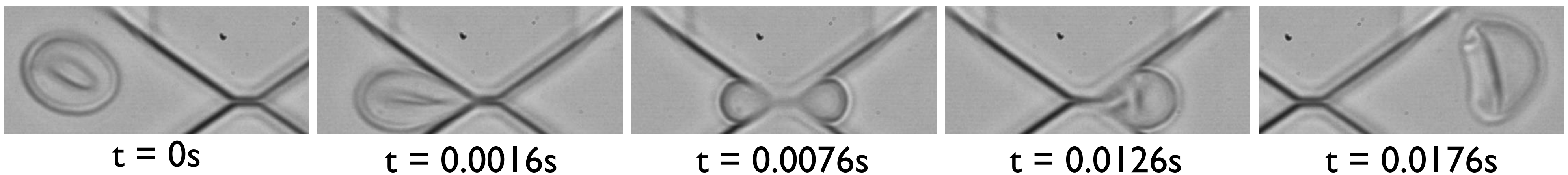
$$f = \bar{f} \quad \text{on} \quad \Gamma^{\mathrm{N}}.$$

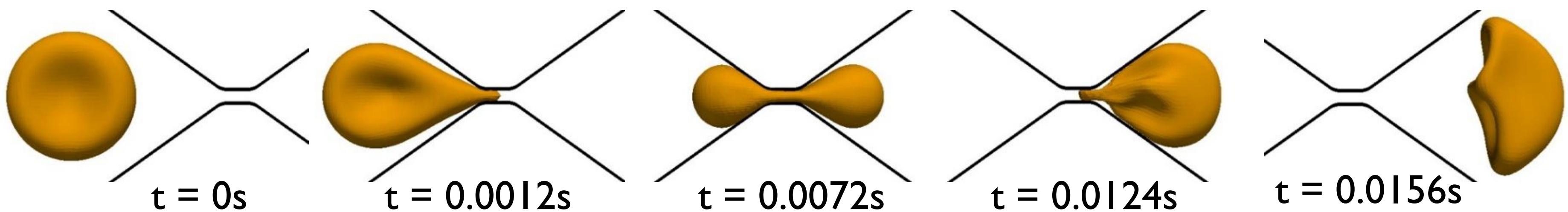
Validation of Cell Deformation and Transit Time against Experiments

Same Condition:

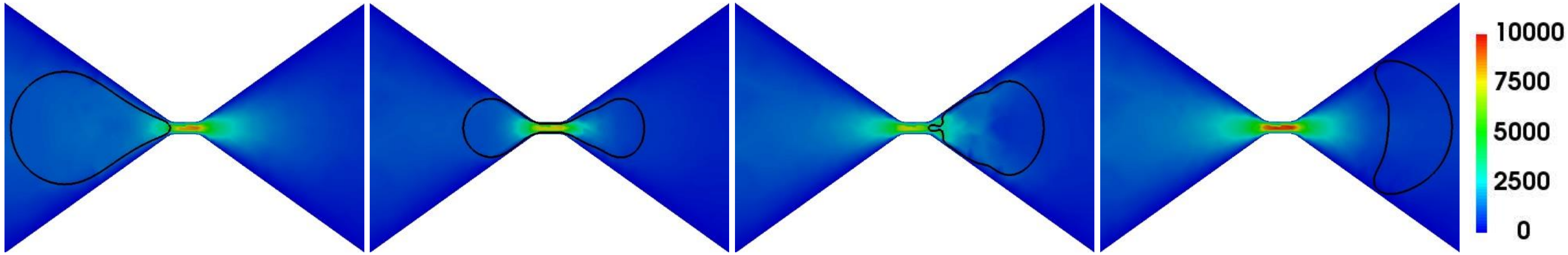
pressure of 831 Pa and same geometry of the channel

(P. Gambhire, A. Viallat *et al*., *Small*, 2017)

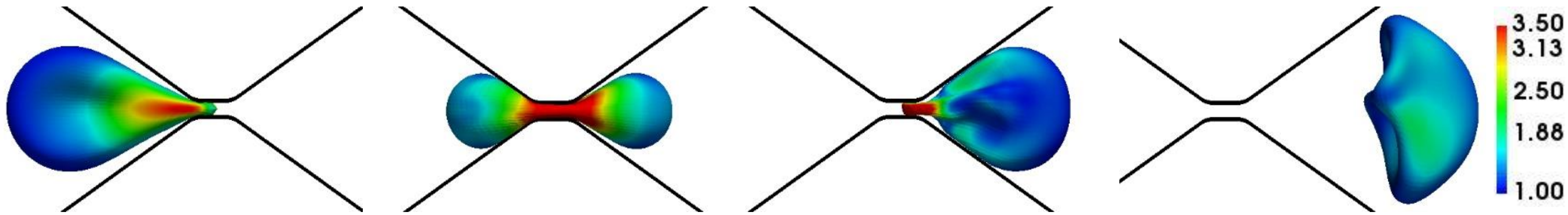




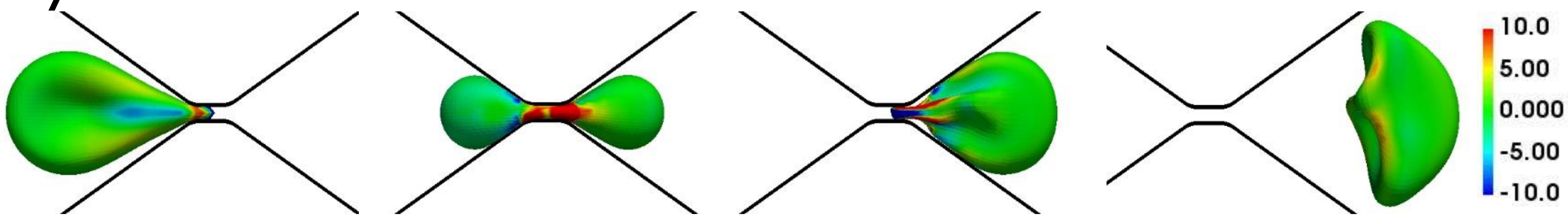
Distribution of Velocity Field



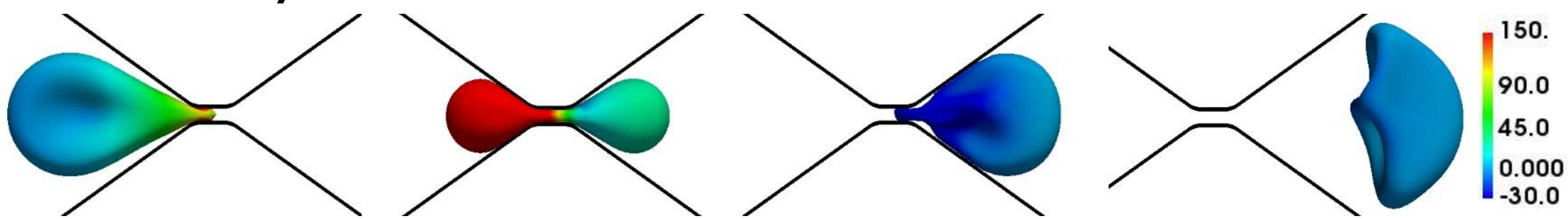
Cytoskeleton Shear Deformation



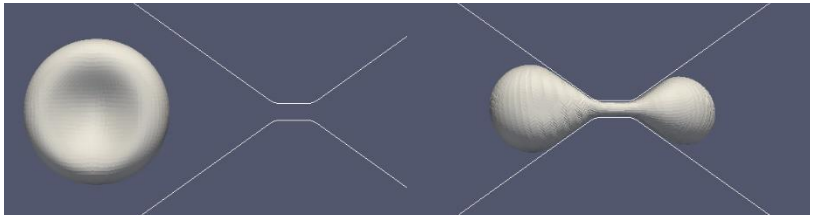
Bilayer-Cytoskeletal Interaction



Tension in the Bilayer

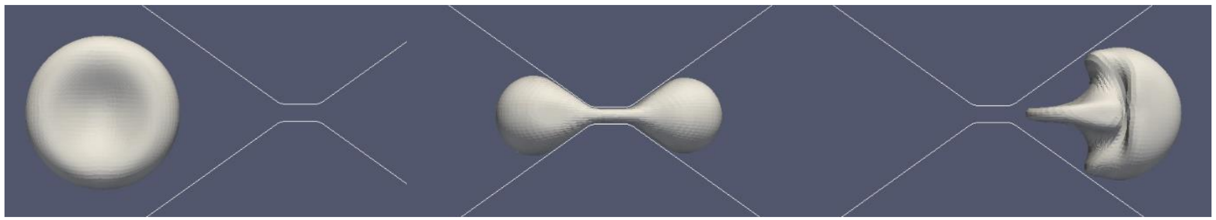


Effect of Surface Area to Volume Ratio

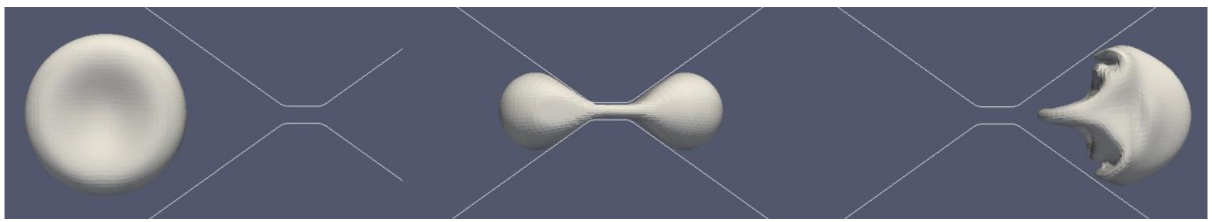


A = 129.078um^3
V = 93.88um^3

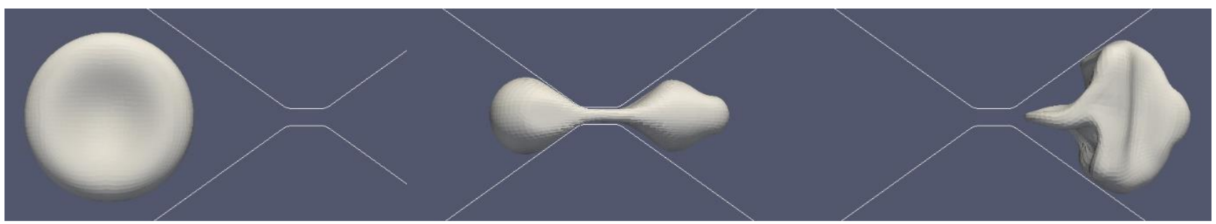
Failed to pass through



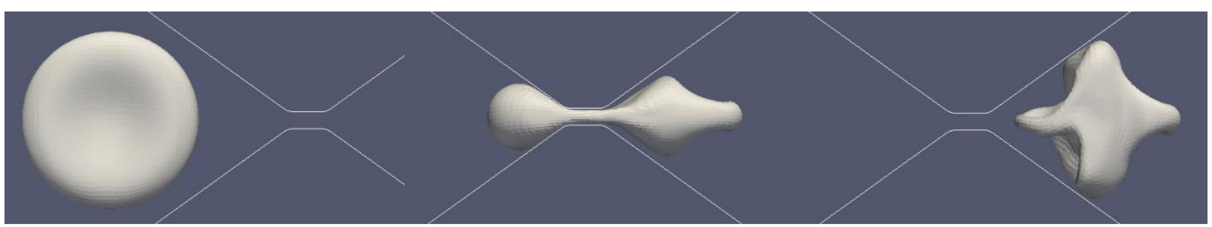
A = 133.90um^3
V = 93.88um^3



A = 139.76um^3
V = 93.88um^3



A = 146.57um^3
V = 93.88um^3



A = 154.27um^3
V = 93.88um^3

Acknowledgement

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Thank you!